

University of Groningen

The corticomedial amygdala and learning in an agonistic situation in the rat

Bolhuis, J.J.; Fitzgerald, R.E.; Dijk, D.J.; Koolhaas, J.M.

Published in:
Physiology & Behavior

DOI:
[10.1016/0031-9384\(84\)90311-1](https://doi.org/10.1016/0031-9384(84)90311-1)

IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.

Document Version
Publisher's PDF, also known as Version of record

Publication date:
1984

[Link to publication in University of Groningen/UMCG research database](#)

Citation for published version (APA):

Bolhuis, J. J., Fitzgerald, R. E., Dijk, D. J., & Koolhaas, J. M. (1984). The corticomedial amygdala and learning in an agonistic situation in the rat. *Physiology & Behavior*, 32(4), 575-579.
[https://doi.org/10.1016/0031-9384\(84\)90311-1](https://doi.org/10.1016/0031-9384(84)90311-1)

Copyright

Other than for strictly personal use, it is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license (like Creative Commons).

The publication may also be distributed here under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license. More information can be found on the University of Groningen website: <https://www.rug.nl/library/open-access/self-archiving-pure/taverne-amendment>.

Take-down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Downloaded from the University of Groningen/UMCG research database (Pure): <http://www.rug.nl/research/portal>. For technical reasons the number of authors shown on this cover page is limited to 10 maximum.

The Corticomedial Amygdala and Learning in an Agonistic Situation in the Rat

J. J. BOLHUIS, R. E. FITZGERALD,¹ D. J. DIJK AND J. M. KOOLHAAS²

Department of Animal Physiology, State University of Groningen
P.O. Box 14, 9750 AA Haren, The Netherlands

Received 17 May 1983

BOLHUIS, J. J., R. E. FITZGERALD, D. J. DIJK AND J. M. KOOLHAAS. *The corticomedial amygdala and learning in an agonistic situation in the rat*. *PHYSIOL BEHAV* 32(4):575-579, 1984.—Social agonistic behaviour of intact male rats is strongly reduced by the experience of defeat by a dominant male conspecific. Small electrolytic lesions in the corticomedial amygdala strongly affected this behavioural change due to defeat. No effects of the lesions were observed before and during the defeat. Some learning is still possible in corticomedial amygdala lesioned animals. A comparison of the effects of lesions made before the defeat with lesions made after the defeat revealed that the lesions primarily produce a retention deficit in social learning.

Corticomedial amygdala Agonistic behaviour Learning

EVIDENCE on the involvement of amygdaloid structures in intraspecific agonistic behaviour in the rat is scarce and often conflicting. Bunnel [3] reported that lesions in the basolateral amygdala of male rats caused a significant decrease in the number of intermale interactions. Using large basolateral amygdala lesions, Busch and Barfield [4] were unable to demonstrate a change in territorial agonistic behaviour. Miczek *et al.* [17] showed that small lesions in the periamygdaloid cortex, the cortical amygdaloid nucleus or the bed nucleus of the stria terminalis strongly reduced agonistic behaviour. Small lesions in the lateral or central nuclei had no effect on this behaviour. Large basolateral amygdala lesions were reported to reduce shock induced fighting [6].

Three major factors may contribute to this confusing picture. First, the locations and the size of the lesions within the amygdaloid complex were different in each of these studies. Second, different test procedures were used to study the effect on agonistic behaviour, for example territorial fighting [4], food competition [17], and shock induced fighting [6]. Finally, Koolhaas *et al.* [15] suggest that the most strong effects of amygdala lesions are obtained in those situations in which learning processes are involved. This idea might explain the positive results by Miczek *et al.* [17] because they used an extensive training procedure to obtain reliable competitive fighting in their test situation.

The hypothesis that the amygdala is mainly involved in learning processes agrees with literature on the role of the amygdala in other types of behaviour [9, 12, 23]. In order to test this hypothesis for agonistic behaviour, we selected a test in which the behaviour was recorded both before, during and after an agonistic experience, i.e., defeat by a dominant opponent. Such a defeat results in a clear change of the behaviour relative to that before the defeat [21]. Since both

Miczek *et al.* [17] and Koolhaas *et al.* [15] found that large lesions in the corticomedial area of the amygdala affected agonistic behaviour, we aimed for this area, but made much smaller lesions restricted to the corticomedial amygdaloid nucleus. Two experiments will be reported in which the lesions were made either before or after the defeat.

EXPERIMENT 1

METHOD

Subjects

Twelve male rats of the WEzob strain (TNO breeding colony) were used as experimental animals (weight 365 ± 8 g). Ten male rats of the same strain (weight 364 ± 7 g) were used as sham operated controls. Two male Tyron maze dull S3 rats of 6 months of age were used as dominant opponents. All experimental and control animals were housed separately in perspex cages ($35 \times 30 \times 15$ cm) with ad lib food and water available. The dominant S3 animals were permanently housed in wooden cages of $80 \times 55 \times 50$ cm together with a ligated female. All experiments were performed in a temperature controlled room (21.5°C) and during the first half of the dark period of the reversed light-dark cycle (12L/12D).

Surgery

At the time of surgery, the animals were anesthetized with ether. Bilateral lesions were made with monopolar stainless steel electrodes with a diameter of 0.2 mm and a sharpened bare cone of 0.1 mm diameter. The lesions were made with an anodal current of 1.5 mA during 5 seconds. The electrodes were aimed at the corticomedial amygdala (coordinates: Anterior 5.0; Lateral 3.5 and Ventral 8.7 mm

¹Supported by a U.K. SRC/NATO Postdoctoral Fellowship.

²Requests for reprints should be addressed to J. M. Koolhaas.

below dura) [16]. In the control animals, the electrode was lowered to 1 mm above the lesion site and no lesion was made.

Experimental Procedure

Eight days after surgery testing was started. The behaviour of the experimental animal towards the dominant opponent which was enclosed in a small wire mesh cage was measured before and after defeat (day -1 and +1) in a large "neutral" test enclosure. This wire-mesh cage prevented direct physical interaction between the dominant and the experimental animal. The experimental animal was placed in the test enclosure ten minutes before the introduction of the wire mesh-cage.

The defeat was in the home cage of the dominant animal (day 0). On this day the experimental animal was placed in the empty home cage of the dominant animal. Ten minutes later the dominant was replaced and the two animals were allowed to interact for ten minutes. The experimental animal was invariably attacked and displayed high levels of submissive postures and flight. The two dominant opponents used were balanced across sham- and lesioned-groups. During the three day test period the experimental animals were housed individually in cages of 30×30×15 cm. The "neutral" test enclosure had a size of 80×55×50 cm and during each test, the floor was covered with fresh filter paper.

Behavioural Observations

On each day, the behaviour of the experimental animal was recorded according to a set of behaviour elements after Grant and Mackintosh [10] and Koolhaas *et al.* [15]. On days -1 and +1, with the dominant enclosed in a wire mesh cage, the following elements were distinguished: explore—exploring any part of the test cage, except the wire mesh cage, explore cage—exploring the wire mesh cage with the dominant in it, groom—any grooming or scratching of the animal, freeze—the animal is completely motionless, no sniffing, occasionally the head moves slightly in a horizontal plane.

During the direct confrontation with the dominant on day 0, the following elements were distinguished (see Koolhaas *et al.* [15] for definitions): upright, attack, investigate, flee, submission, freeze.

Histology

After the experiments, the animals were deeply anesthetized with barbiturates and perfused with saline followed by a 4% formaldehyde solution. Frozen sections of 40 μ m were cut and stained with cresyl violet.

Statistics

For between group comparisons, the Kruskal-Wallis one-way analysis of variance, and the Mann-Whitney U test were used. For within subject comparisons, the Wilcoxon Matched-pairs signed rank test was used [25].

RESULTS

Two experimental animals had a unilateral lesion and were disregarded for further analysis. Figure 1 shows the histology of the remaining 10 lesioned animals. All lesions caused damage to the corticomedial amygdala, whereas damage to other amygdaloid structures was minimal. A be-

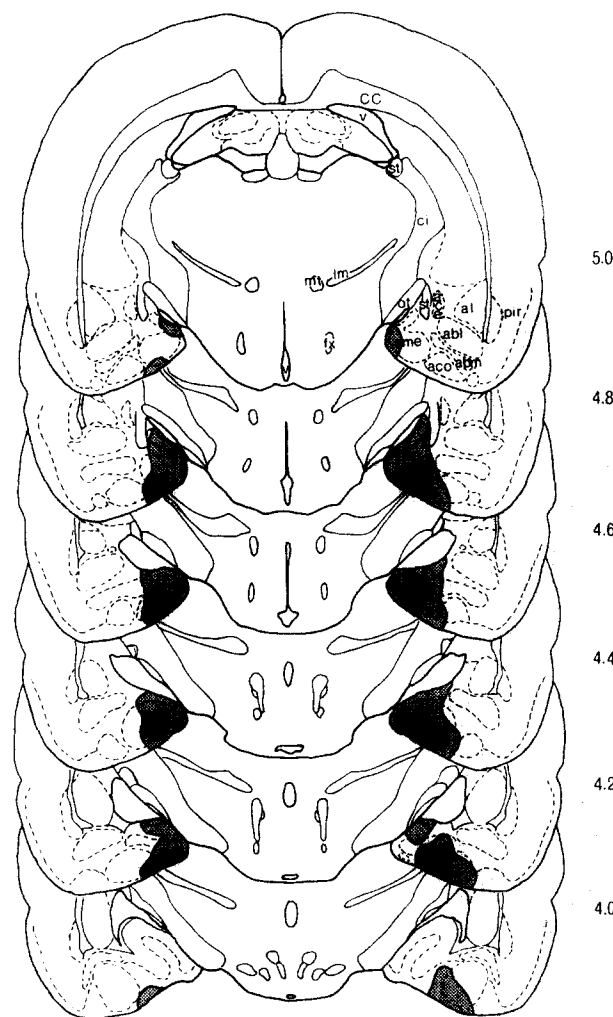


FIG. 1. Coronal sections of the rat brain [16] showing a representative lesion (black) and the total area covered by the lesions (gray).

tween groups comparison revealed that the pre-defeat behaviour of both groups of experimental animals was the same. Also during the defeat (Table 1), there was no significant difference between the lesioned animals and the sham-lesioned controls, although the lesioned animals seem to show somewhat less freezing.

The behavioural change due to this defeat is given in Fig. 2. Both in the lesioned animals and the sham lesioned controls, there was a significant increase in freezing ($p < 0.002$) and a decrease in sniff cage ($p < 0.002$) after the defeat. The changes in explore and groom were in the same direction in both groups of animals but reached significance ($p < 0.002$) in the sham lesioned controls only.

Although the changes in behaviour after the defeat were in the same direction in both groups of animals, there were significant differences between the two groups. The lesioned animals perform significantly less freezing, exploring, and sniff cage than the control animals (Fig. 2).

A detailed analysis of the post defeat behaviour revealed a positive correlation ($r_s = 0.68$, $p < 0.05$ Spearman rank correlation) between freeze on the day after defeat and the amount of time spent fleeing during the defeat in the lesioned animals. In the sham lesioned controls the correlation was

TABLE 1
PERCENTAGE OF TIME (\pm SEM) SPENT ON VARIOUS BEHAVIOURS DURING
DEFEAT IN THE HOME CAGE OF THE DOMINANT ANIMAL
(Aco/Me=CORTICOMEDIAL AMYGDALA)

	Shams N=10	Aco/Me N=10	Significance
Upright Posture	16.0 \pm 4.3	21.8 \pm 5.7	ns
Attack	4.6 \pm 0.8	6.2 \pm 1.2	ns
Investigate	2.2 \pm 0.9	1.7 \pm 0.5	ns
Flight	3.8 \pm 1.2	6.0 \pm 1.4	ns
Submission	30.7 \pm 7.0	33.7 \pm 6.7	ns
Freeze	37.5 \pm 9.2	28.7 \pm 8.9	ns

very low ($r_s = -0.11$), since these animals spent a maximum amount of time freezing, irrespective of the behaviour during defeat.

DISCUSSION

This experiment clearly shows that corticomedial amygdala lesions had no significant effect on behaviour either towards a caged conspecific before defeat or on ongoing behaviour during defeat. However, marked deficits were observed in the behavioural change produced by a severe agonistic experience, in this case defeat by a dominant animal. Corticomedial amygdala lesioned animals do change their behaviour after the defeat but less strongly than the control animals. This observation is consistent with the partial deficits in taste aversion observed after amygdala lesions in other conditioning experiments [1, 8, 18, 19].

An intriguing result is the correlation between behaviour during and after defeat in the lesioned animals. We have noted a similar relationship between the strength of conditioning and the resulting change in behaviour in taste aversion learning after amygdala lesions [23] or lateral hypothalamic stimulation [7]. Apparently learning is still possible in amygdaloid lesioned animals.

It can be concluded that corticomedial amygdala lesions result in a partial deficit in the behavioural change produced by defeat. Since the lesions did not affect behaviour before and during defeat, this change may be interpreted as a deficit in social learning.

EXPERIMENT 2

In the interpretation of the results of Experiment 1 in terms of a partial learning deficit, the question arises as to whether acquisition or retention processes are affected by the lesions. In order to answer this question, the animals in this experiment were lesioned after the defeat.

METHOD

Subjects

Thirteen naive animals as in Experiment 1 were used as sham operated controls, 8 animals were lesioned in the corticomedial amygdala.

Experimental Procedure

Five days prior to the start of the experiments the animals were housed individually in perspex cages of 35 \times 30 \times 15 cm. All animals were defeated in the home cage of a heavy male

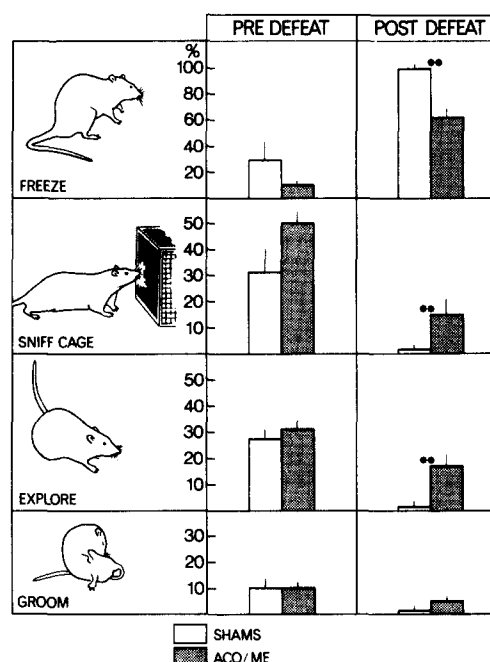


FIG. 2. Relative time spent on some behaviours for the two groups of experimental animals (**= $p < 0.02$).

S3 rat on day 0. The day before this defeat and on day 1 and 2 after defeat, all animals were tested in the presence of their dominant opponent as in Experiment 1. Surgery was performed three days after defeat. Sham and lesioned groups were balanced for behaviour on day 0 and +1. On day 7 and 8 post defeat tests were carried out, again in the presence of the dominant opponent enclosed in a small wire-mesh cage. The behavioural analyses are based upon day -1, +1 and +7.

RESULTS

A reconstruction of the lesions revealed that the corticomedial amygdala lesions were highly similar to those of Experiment 1. The behavioural effects of the lesions is presented in Fig. 3. Since sham and lesioned groups were balanced, there was no difference between the two groups in pre defeat (day -1) and post defeat (day +1) behaviour. However, after the lesion (day +7) the behaviour of the

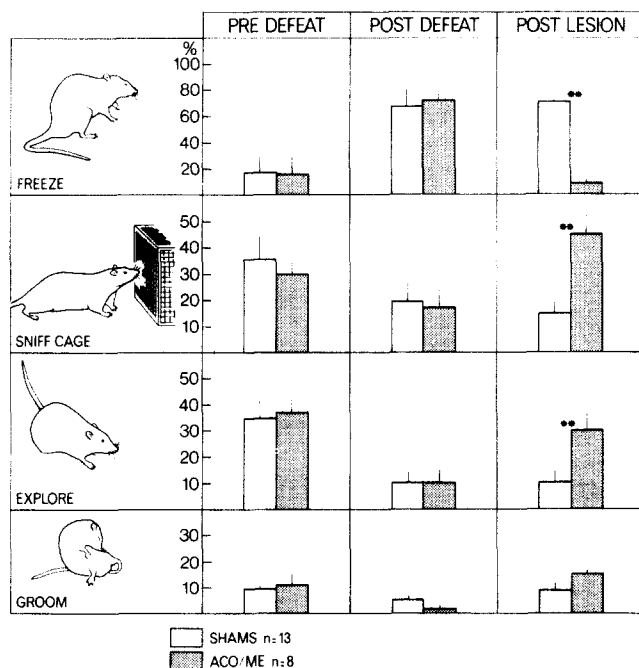


FIG. 3. Relative time spent on some behaviours for the two groups of experimental animals in the three phases of the experiment (**= $p < 0.02$).

amygdaloid lesioned animals was significantly different from the post lesion behaviour of the sham group (Fig. 3). In the sham group there was no difference in behaviour between day +1 (post defeat) and day +7 (post op) indicating that the defeat results in a behavioural change lasting for at least one week. Lesions in the corticomedial amygdala resulted in a significant decrease in freeze ($p < 0.02$) and an increase in sniff cage ($p < 0.02$) and explore ($p < 0.05$). A comparison of the behaviour after the amygdaloid lesion with that on day -1 (pre defeat) revealed no statistical differences between the two days for any behaviour.

DISCUSSION

This experiment confirms the conclusion of Experiment 1 that the corticomedial amygdala is involved in the behavioural changes normally observed after a defeat. Since the lesions were made after the defeat the deficit observed must be due to an effect on retention of social learning. This deficit is apparently complete, because the amygdaloid lesioned animals behaviour was the same as before defeat. This is in contrast with the results of Experiment 1 in which only a partial deficit was found. This difference between the two experiments may be due to a difference in the acquired defeat, rather than the moment of the lesion. However, the suggestive trend in the post defeat behaviour of the sham operated controls in the two experiments is not significant. Moreover, the relative difference between the shams and the lesioned animals in post defeat freezing behaviour differs strongly between the two experiments (35% in Experiment 1 and 89.5% in Experiment 2). Therefore, the differences between the two experiments in the effects of the lesions seem to be due to the moment of the lesion relative to the acquisition of the defeat. Similar differences in lesion effects were reported by Nachman and Ashe [18] in a conditioned taste

aversion experiment whereby lesions before conditioning produced a partial deficit, but lesions after conditioning a total deficit.

It is concluded that corticomedial amygdala lesions produce a complete loss of retention of information necessary for the behavioural adaptation to a changing agonistic situation.

GENERAL DISCUSSION

The present experiments demonstrate that the corticomedial amygdala is involved in the behavioural change produced by a defeat in an agonistic interaction. The results are comparable to the effects of amygdala manipulations in shock avoidance and taste aversion learning situations, because in all these situations deficits in behavioural changes guided by previous experience are observed. The results in these situations have been explained by a wide variety of terms and concepts. For example, the effects of amygdala manipulations in avoidance situations have been interpreted in terms of reduced fear or reduced emotionality [26,28]. Also the term response suppression or performance deficit is used [5,19]. Again others [18] explain their results in taste aversion experiments in terms of a reduced capacity of amygdala lesioned animals to identify the significance or meaning of stimuli. Most of these interpretations are not mutually exclusive and often hard to separate experimentally. Because there is a small trend for less freeze in the pre defeat and during defeat behaviour of the lesioned animals, the results might be explained by a "reduced fear" hypothesis. However, this trend is not significant and such a hypothesis does not explain the differences in lesion effect of the two experiments. An interpretation in terms of learning and memory processes seems to explain most of the data. Similar interpretations were used by several other authors [12, 22, 23]. In these terms, the lesion made after the defeat creates a complete retention deficit. We may speculate therefore that the corticomedial amygdala is involved in agonistic behaviour because of its mediation in social learning processes. This is consistent with the more general suggestion found in the literature on rats, cats and monkeys, that the amygdala is involved in the evaluation of the present situation in relation to past experience [9, 13, 27]. Since lesions in the corticomedial amygdala also reduce sexual behaviour in experienced male rats [11], it seems that this structure is important in any kind of social behaviour.

The partial deficit in the lesioned animals in Experiment 1, and the fact that the behaviour of these animals was still related to the behaviour during defeat, shows that some learning is still possible in the lesioned animals. Hence, also other brain structures than the corticomedial amygdala may become involved in this social learning. The identity of these structures, and the question how they are involved in social learning remains a matter of further research.

The corticomedial amygdala may be quite specifically involved in social learning processes. Miczek *et al.* [17], using control lesions in other amygdaloid structures observed changes in food competition aggression in the corticomedial amygdala lesioned animals only. Our own studies with small lesions within the corticomedial area indicate that the most effective area is the medial amygdala and the amygdala hippocampal transition zone; lesions in the cortical nucleus are ineffective [14]. The suggested specificity is supported by the neuroanatomical connections of this area. The corticomedial amygdala is one of the major areas of the vomeronasal organ

[24]. This part of the olfactory system seems to be involved in the perception of species specific odours and may be important for social behaviour. The corticomedial amygdala is also reciprocally connected to the ventral premammillary nucleus and the medial preoptic area [16] which are reported to be important structures in aggressive behaviour [2,15]. However, the relevance of these connections for the functioning of the amygdala remains unknown.

In summary, lesions in the corticomedial nucleus of the amygdala seem to affect learning processes in agonistic situations. The fact that a learning process must be included in the test situation together with the fact that the effect can be obtained with discrete corticomedial amygdaloid lesions might explain the contradictory literature on the amygdala and aggressive behaviour in the rat mentioned in the general introduction.

REFERENCES

- Aggleton, J. P., M. Petrides and S. D. Iversen. Differential effects of amygdaloid lesions on conditioned taste aversion learning by rats. *Physiol Behav* 27: 397-400, 1981.
- Berg, M. v. d., G. J. ter Horst and J. M. Koolhaas. The nucleus premammillaris ventralis (PMV) and aggressive behaviour in the rat. *Aggress Behav* 9: 41-47, 1983.
- Bunnell, B. N. Amygdaloid lesions and social dominance in the hooded rat. *Psychon Sci* 6: 93-94, 1966.
- Busch, D. E. and R. J. Barfield. A failure of amygdaloid lesions to alter agonistic behavior in the laboratory rat. *Physiol Behav* 12: 887-892, 1974.
- Campenot, R. B. Effect of amygdaloid lesions upon active avoidance acquisition and anticipatory responding in rats. *J Comp Physiol Psychol* 69: 492-497, 1969.
- Eichelman, B. S. Effect of subcortical lesions on shock-induced aggression in the rat. *J Comp Physiol Psychol* 74: 331-339, 1971.
- Ettenberg, A., A. S. Sgro and N. White. Algebraic summation of the affective properties of a rewarding and an aversive stimulus in the rat. *Physiol Behav* 28: 873-877, 1982.
- Fitzgerald, R. E. and M. J. Burton. Neophobia and conditioned taste aversion deficits in the rat produced by undercutting temporal cortex. *Physiol Behav* 30: 203-206, 1983.
- Gloor, P. Inputs and outputs of the amygdala: what the amygdala is trying to tell the rest of the brain. In: *Limbic Mechanisms*, edited by K. E. Livingston and O. Hornykiewicz. New York: Plenum Press, 1978, pp. 189-209.
- Grant, E. C. and J. H. Mackintosh. A comparison of the social postures of some common laboratory rodents. *Behaviour* 11: 246-259, 1963.
- Harris, V. S. and B. D. Sachs. Copulatory behaviour in male rats following amygdaloid lesions. *Brain Res* 86: 514-518, 1975.
- Kaada, B. R. Stimulation and regional ablation of the amygdaloid complex with reference to functional representations. In: *The Neurobiology of the Amygdala*, edited by B. E. Eleftheriou. New York: Plenum Press, 1972, pp. 205-281.
- Kling, A. Influence of temporal lobe lesions on radio-telemetered electrical activity of amygdala to social stimuli in monkey. In: *The Amygdaloid Complex*, edited by Y. Ben-Ari. Amsterdam: Elsevier/North Holland, 1981, pp. 271-280.
- Koolhaas, J. M. The corticomedial amygdala and the behavioural change due to defeat. In: *Modulation of Sensorimotor Activity During Altered Behavioural States*, edited by R. Bandler. New York: Alan R. Liss, (in press).
- Koolhaas, J. M., T. Schuurman and P. R. Wiepkema. The organisation of intraspecific agonistic behaviour in the rat. *Prog Neurobiol* 15: 247-268, 1980.
- Krettek, J. E. and J. L. Price. Amygdaloid projections to subcortical structures within the basal forebrain and brainstem in the rat and cat. *J Comp Neurol* 178: 225-254, 1978.
- Miczek, K. A., T. Brykzyski and S. P. Grossman. Differential effects of lesions in the amygdala, periamygdaloid cortex and stria terminalis on aggressive behaviors in the rat. *J Comp Physiol Psychol* 87: 760-771, 1974.
- Nachman, M. and J. H. Ashe. Effects of basolateral amygdala lesions on neophobia, learned taste aversions and sodium appetite in rats. *J Comp Physiol Psychol* 87: 622-643, 1974.
- Pellegrino, L. Amygdaloid lesions and behavioral inhibition in the rat. *J Comp Physiol Psychol* 65: 483-491, 1968.
- Pellegrino, L. J. and A. J. Cushman. *A Stereotaxic Atlas of the Rat Brain*. New York: Appleton-Century-Crofts, 1967.
- Poll, N. E. van de, F. de Jonge, H. G. van Oyen and J. van Pelt. Aggressive behaviour in rats: effects of winning or losing on subsequent aggressive interactions. *Behav Proc* 7: 143-156, 1982.
- Richardson, J. S. The amygdala: historical and functional analysis. *Acta Neurobiol Exp* 33: 623-645, 1973.
- Rolls, B. J. and E. T. Rolls. Effects of lesions in the basolateral amygdala on fluid intake in the rat. *J Comp Physiol Psychol* 83: 240-247, 1973.
- Scalia, F. and S. S. Winans. The differential projections of the olfactory bulb and accessory olfactory bulbs in mammals. *J Comp Neurol* 161: 31-56, 1975.
- Siegel, S. *Nonparametric Statistics for the Behavioral Sciences*. Tokyo: McGraw-Hill, 1956.
- Spevack, A. A., C. T. Campbell and L. Drake. Effect of amygdalotomy on habituation and CER in rats. *Physiol Behav* 15: 199-207, 1975.
- Vergnes, M. Effect of prior familiarization with mice on elicitation of mouse-killing in rats: role of the amygdala. In: *The Amygdaloid Complex*, edited by Y. Ben-Ari. Amsterdam: Elsevier/North Holland, 1981, pp. 293-304.
- Werka, T., J. Skår and H. Ursin. Exploration and avoidance in rats with lesions in amygdala and piriform cortex. *J Comp Physiol Psychol* 92: 672-681, 1978.
- Winans, S. and J. B. Powers. Olfactory and vomeronasal deafferentiation of male hamsters: Histological and behavioral analyses. *Brain Res* 126: 325-344, 1977.